Offshore structures under special loads including Fire resistance
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Lecture - 22
Impact and Non-Impact Wave Loads-II

Friends, in today's lecture we will continue to discuss what we had left in the last lecture, where we are looking now the response of compliance structures under impact and non impact wave loads just for continuity.

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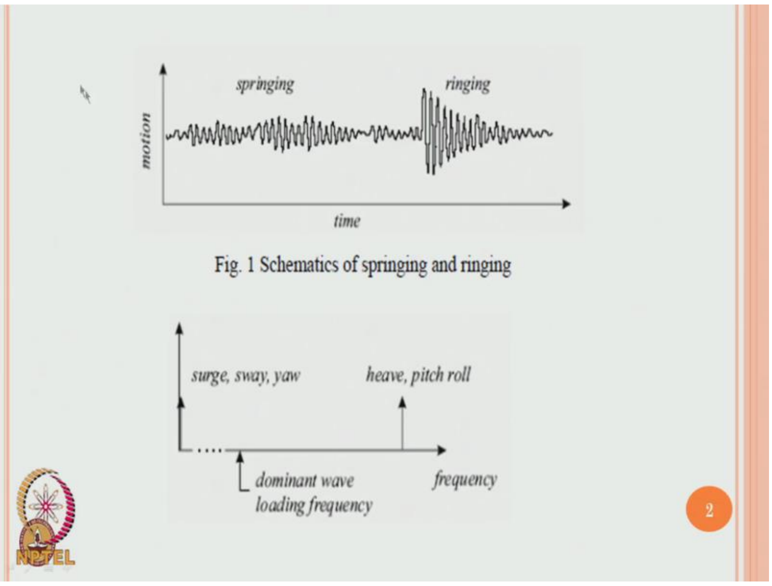

We said that springing and ringing are different kinds of wave simulated, which can cover a wide range of frequency, which can also activate even the soft degrees or the compliant degrees as well as the stiff degrees in a hybrid system like TLP.

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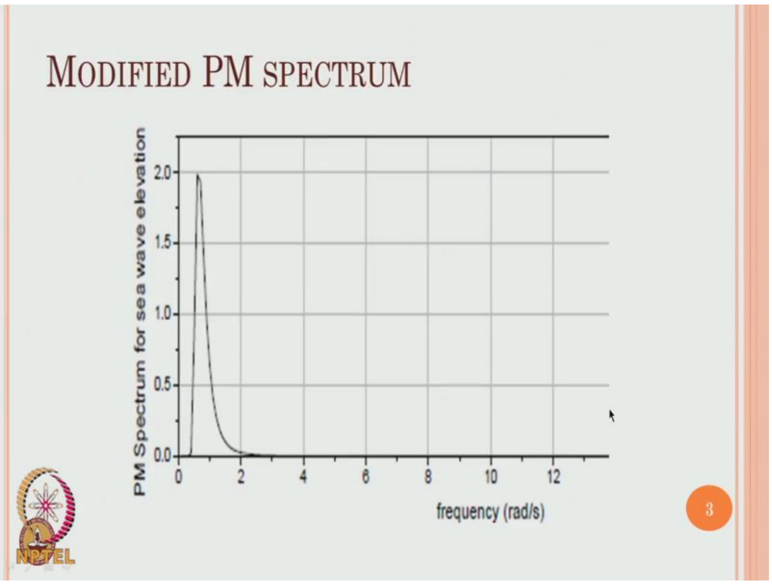

These waves can be generated by modifying the Pierson Moskowitz spectrum, which was originally the wind velocity; however, it has been modified to be a model frequency and the frequency has been chosen 5 times closer to the rather such frequency of the platform, to initiate the impact and non impact waves.

So, impact waves will have a distinct wave height compared to the preceding and the following wave whereas, non impact waves will result in a transient response which we can easily generate using the sea surface elevation proposed by the equations in the last lecture.

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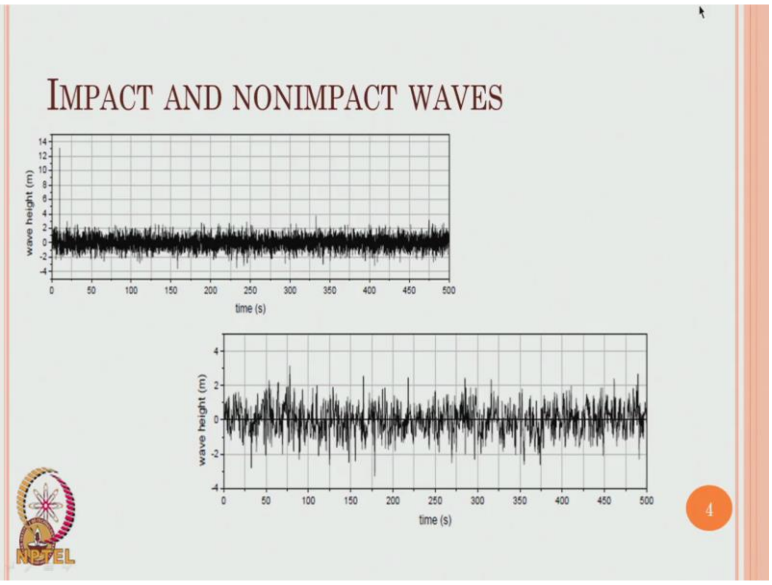

A typical impact wave and the non impact wave looks like this other time history, you can see a very clearly that the impact wave has a distinctly high wave height compared to the preceding in the following waves whereas, this is a transient respond wave or a non impact wave which can cause a transient response, which is also interesting for us to understand. So, they are attributed as springing and ringing responses in a given offshore platform which will discussed in detail.

We picked up also a triangular geometry TLP with 2 basis of equivalency with respect to the rectangular or a square TLP, keeping initial tension in every tendon same that maybe the first logic. The second logic is keeping the total T 0 same; however, we are changing the pay load or the weight of the system.

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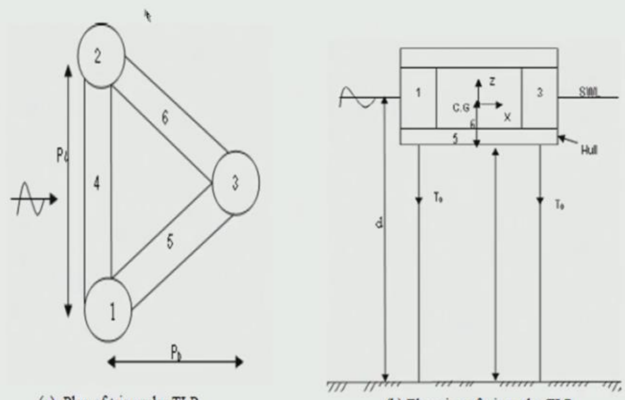

(a) Plan of triangular TLP

(b) Elevation of triangular TLP

This was the conceived geometry of a triangular configuration, with 3 column members and 3 (Refer Time: 02:48) members connecting the column member, these are the standard dimensions and conventions has been used in the analysis.

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Table 1 Geometric properties of square TLPs considered

Property	Case 1	Case 2	Case 3	Case 4
Weight (kN)	351,600.00	330,000.00	330,000.00	370,000.00
F_B (kN)	521,600.00	465,500.00	520,000.00	625,500.00
T_0 (kN)	170,000.00	135,500.00	190,000.00	255,500.00
Tether length, ℓ (m)	568.00	269.00	568.00	1,166.00
Water depth (m)	600.00	300.00	600.00	1,200.00
CG (m)	28.44	27.47	28.50	30.31
AE/ℓ (kN/m)	84,000.00	34,000.00	82,000.00	45,080.00
Plan dim (m)	70.00	75.66	78.50	83.50
D and D_c (m)	17.00	16.39	17.00	18.80
r_x (m)	35.10	35.10	35.10	35.10
r_y (m)	35.10	35.10	35.10	35.10
r_z (m)	35.10	42.40	42.40	42.40

Table 2 Natural wave periods and frequencies of equivalent triangular TLPs with T_0 per tether same

Case	Natural time period (s)			Natural frequency (Hz)		
	Surge	Heave	Pitch	Surge	Heave	Pitch
TLP_1	98.00	1.92	2.110	0.0102	0.5208	0.4739
TLP_2	87.20	1.96	2.155	0.0115	0.5102	0.4640
TLP_3	97.00	1.92	2.060	0.0103	0.5208	0.4854
TLP_4	132.0	3.11	3.120	0.0076	0.3215	0.3205

These are 4 cases of triangular square TLP’s taken for the consideration at almost same water depths, but the marginal variation in axel the tension and a marginal variation in size at about half the depth and about double the depth, so that we want to see what would be the effect of various parameters on the equivalent triangular geometry under the influence of impact and non impact waves.

So, for every square TLP of case 1; we generated 2 equivalent set of triangular TLP’s. For example one set of equivalent triangular TLP refers to initial pretension in every tether being same compared to that of square and triangular of configuration. So, case 1 refers to back a TLP 1, TLP 2 for case 2 and so on and so forth. One can see the natural periods estimated here and the corresponding frequency in hertz for this platform of an equivalent triangular geometry.

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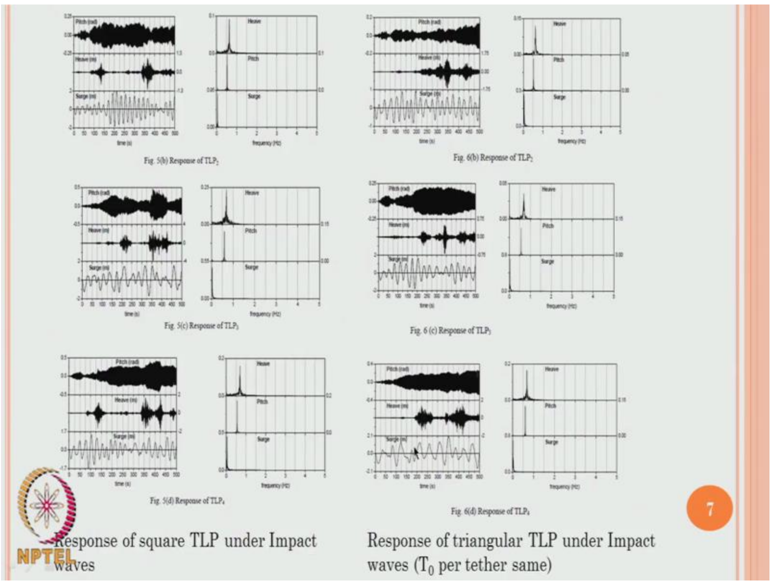

We said that springing wave and ringing wave are simulated wave loads, which can activate both flexible and stiff degrees of freedom. Let us look at a typical response of one of the equivalent triangular TLP.

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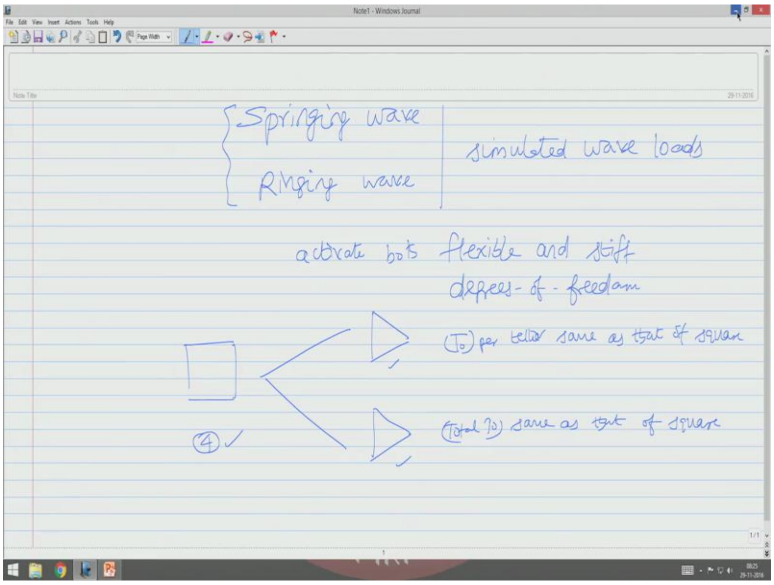

We have a square TLP, we arrived at 2 equivalent triangular TLP’S, this can be T 0 per tether same as that of square, this can be total T 0 same as that of square so 4 squares TLP’s existing in gulf or Mexico or chosen and 2 equivalence sets of triangular configuration or arrive an analysis is done on these TLP’s under the springing and ringing waves generated or simulated with equations shown to you.

Now, let us look at the responses; please look at the screen now you will find the response of equivalency of TLP 2, 3 and 4, pitch heave and surge time history and the corresponding power spectral density functions of heave pitch and surge I am sorry for the order, but one can easily relate, similarly, for these 3 degrees of freedom for TLP 3 and TLP 4.

One can also look at the response comparison of a square TLP under impact waves with that of equivalent triangular TLP with an impact wave, the equivalency of these results are arrive by keeping T0 per tether same between the triangular TLP’s with that of an equivalent square TLP. So, one can look at these figures and try to let us for completion.

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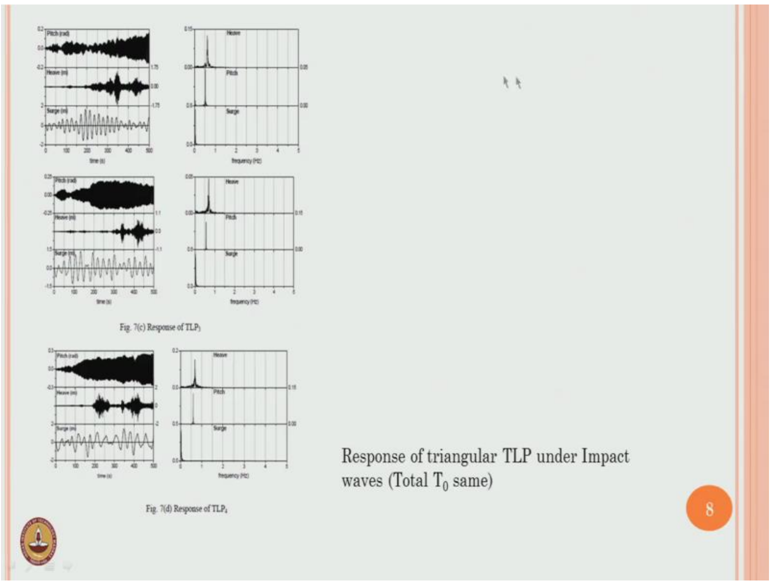

Let us also look into the fourth set; for keeping T 0 total T 0 same we also get the responses in pitch, heave and surge degrees we are looking for (Refer Time: 07:31) directional wave therefore, square response is absent for the wave predominant direction being along x axis roll response is also absent. For the platform being symmetrical in nature yaw response is also not present significantly therefore, we looking only for those 3 degree of freedom which are active in nature, surge response, heave response and pitch response time history and corresponding power spectral density functions in frequency domain of these responses.

Please look at the figures now the lefty hand side set shows the response of square TLP under non impact waves whereas, equivalent response of triangular TLP's for T 0 per tether same and total T 0 being same or now shown on the screens in parallel.

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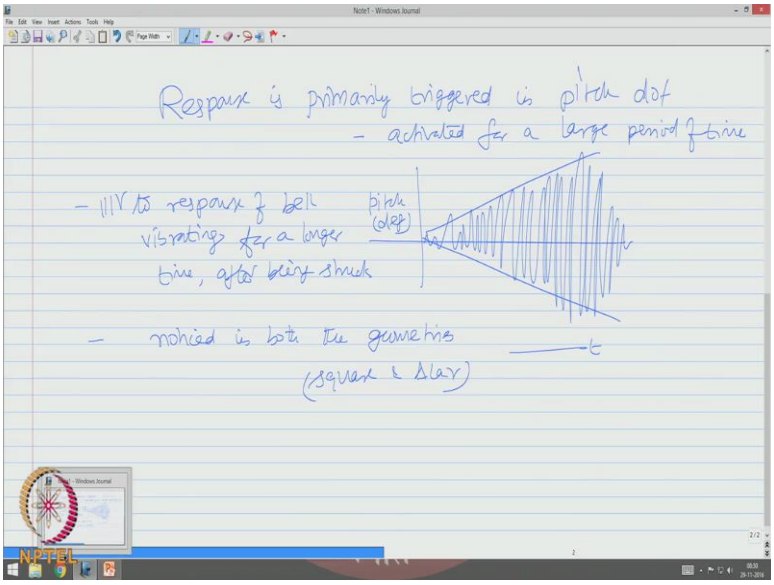

Looking at these responses, one can say that response is primarily triggered in pitch degree of freedom, if you look at the curves back you will realize that pitch degree is becoming highly active compared to heave and surge degrees of freedom, both in square as well as equivalent triangular TLP models. This is activated for a large period of time. If we look at the typical response, the typical response may look dens may grow like this, one can say that the response is more or less similar to the response of f bell vibrating for a longer time was is the time is t this is the pitch response in degrees, after being struck. So, similar response is noticed in both the geometries that is square as well as triangular configuration.

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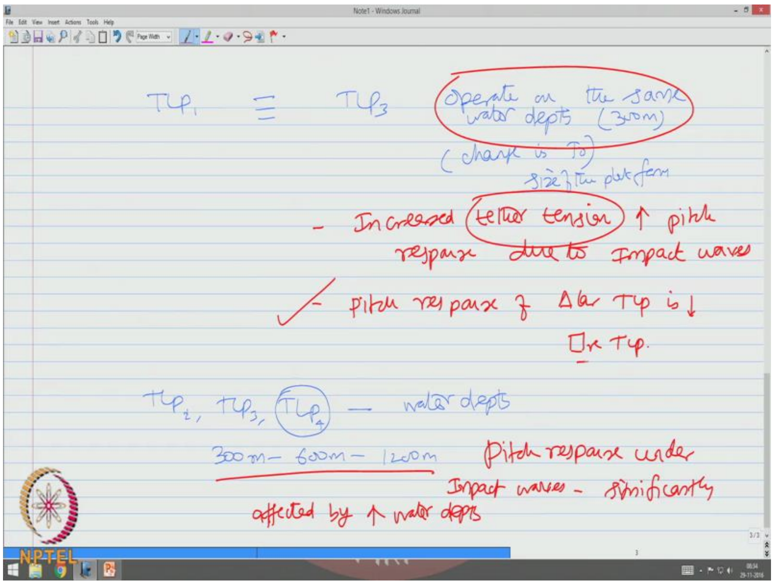

Now, let us try to compare these responses for deferent water depths, let us pick up TLP 1 and TLP 3, you can realize that both of them operate on the same water depth, of course there is difference in initial tension and the size of the platform marginally, but water depth is same this 300 meters. So, one can now say increased tether tension enhances the pitch response, due to impact waves. One can also notice that the pitch response of triangular configuration is lesser compared to square configuration. If you now compare TLP 1, TLP 2 and TLP 4, let us say 2, 3 and 4 let us compare to TLP 3 and 4.

One can see here that water depth changes between these configurations, it increases from 300 meters, to 600 meter to further 1200 meter was TLP 4 is a deepest platform what we are analyzing in the present study. So, in these cases pitch response under impact waves is significantly affected by increase in water depth. Please note for the same water depth pitch response is influenced by increase in tether tension, for increase in water depth pitch response also influenced. In this case fortunately this statement still holds good, triangular TLP responses in all the cases equivalency are found to be lesser than that of a square TLP.

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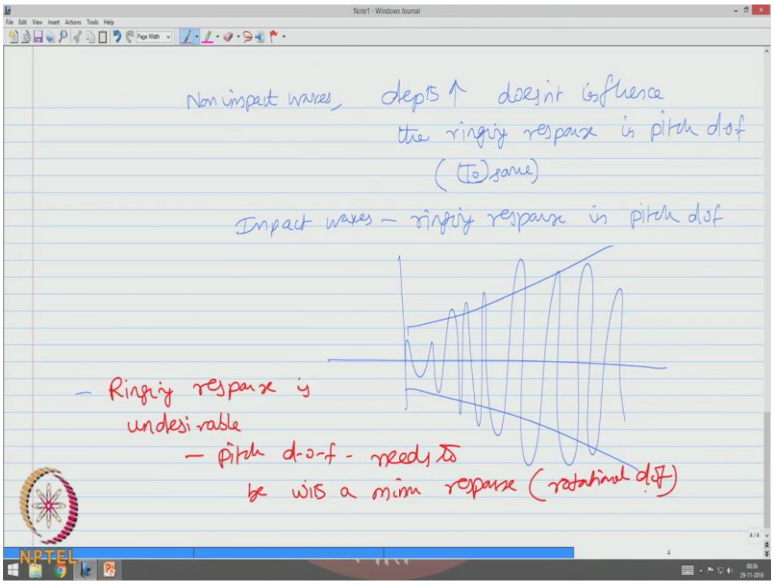

If you look at the response for non impact waves, I should say that increase in water depth does not influence the ringing response, in at least pitch degrees of freedom, this expressly true when you keep T 0 same. So, impact waves cause ringing response in pitch degrees of freedom because the typical response look like ringing of the bell response. Ringing response is undesirable because pitch degree of freedom needs to be with the minimum response the reason being it is one of the rotational degrees of freedom.

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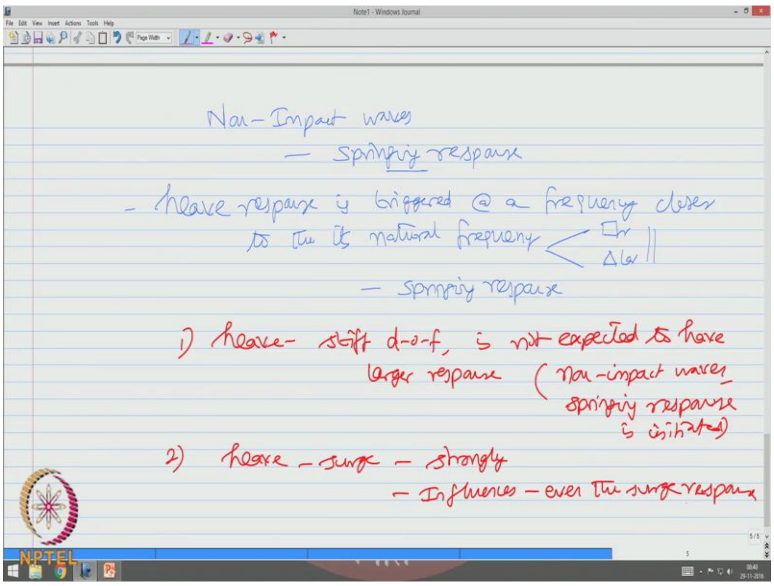

Let us talk about non impact waves, they cause springing response. Let us look at the time history of these responses, once again these are the typical time history response and the corresponding power spectral density function in frequency domain of square as well as equivalent triangular TLP'S and the non impact waves for 2 different established cases, T 0 per tether being same or T 0 total being same between the triangular configurations and the existing square configurations of the platform; which very interesting that heave response is being triggered in both square as well as triangular TLP's, near to the natural frequency of that of the one causing spring response. So, one can say that heave response is triggered at a frequency closer to its natural frequency of the system, this is true in both square and equivalent triangular, this causes what we call as springing response.

So, friends heave being a stiff degree is not expected to have large response, but under non impact waves springing response is initiated that is the first draw back we have under non impact waves. The second one heave we know is coupled with surge degree of freedom very strongly. So, this influences even the surge response as well, one can also see that heave response has got a broad band, heave response is broad band frequency commonly noticed in both the geometries; square as well as equivalent triangular TLP's of various water depths are TLP 2, 3 and 4 respectively.

By comparing the springing response in heave degree of freedom with TLP 3 and 1, one can easily see that the heave response decreases with increase in tension. If you compare the heave response for different TLP's at different water depths, one can also see that the heave response increases again with increase in water depth compared to TLP 2, 3 and 4. 3 is at 600 meter, TLP 2 is half of that, TLP 4 is double of this. So, one can very easily see the water depth also increases the stiff degree of freedom which is heave response.

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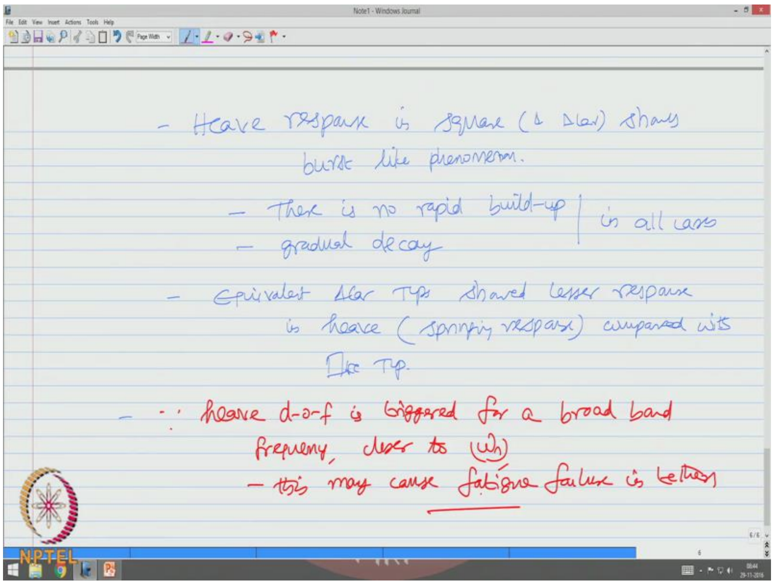

So, heave response in both square and triangular shows burst phenomena. The only good thing about is there is no rapid buildup, it is got a gradual decay in all cases. Comparatively equivalent triangular TLP’s showed lesser response in heave degree or I should say lesser springing response comparison or compared with square TLP. So, there is a very dangerous phenomena which happens here, since heave degree is triggered for a broad band frequency and it is also closer to the natural frequency this may cause fatigue failure in tethers.

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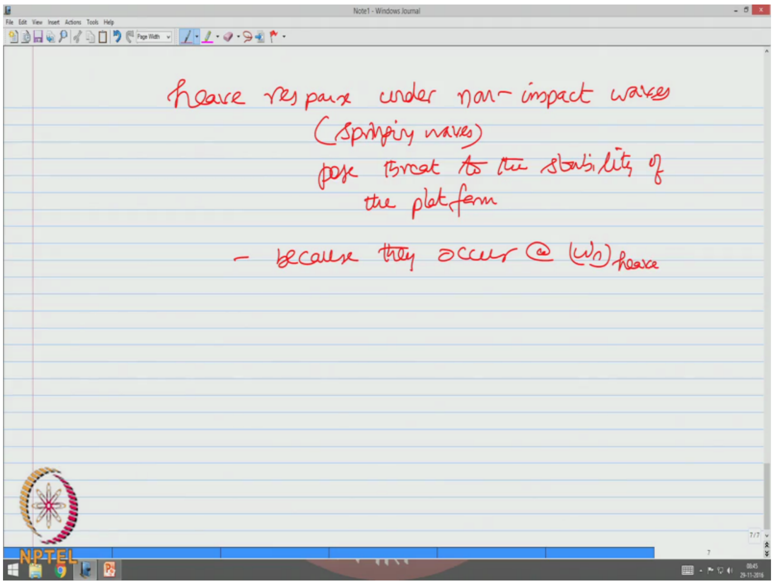

Therefore one can say heave response under non impact waves, which we call as springing waves, pose threat to the stability of the platform because they occur at a frequency closer to heave degree of freedom natural frequency.

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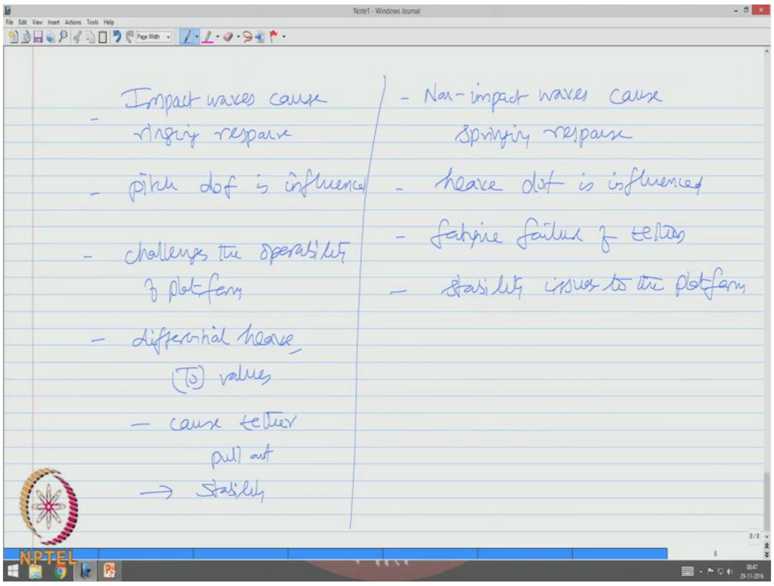

So, friends one can say that impact waves cause ringing response, non impact waves cause springing response. In ringing response pitch degree of freedom is influenced, in springing response heave degree of freedom is influenced. This can result in fatigue failure of tethers, it can also cause stability issues to the platform, pitch degree of freedom being rotational challenges, the operability of the platform which also causes differential heave which in turn will affect T 0 values, which can also cause tether pull out which can also result in stability issues.

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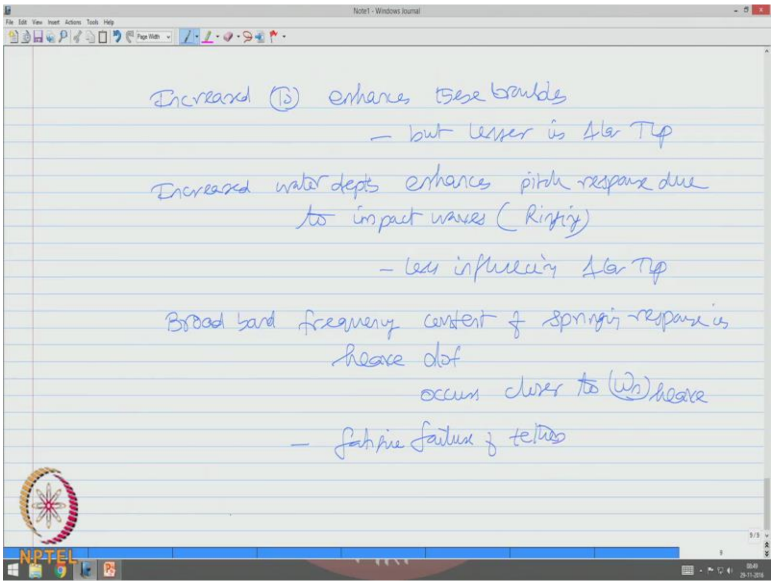

Increased tether tension enhances these troubles, but lesser in triangular configuration. Increased water depth enhances pitch response due to impact waves which is ringing, but less influencing the triangular TLP. Broad band frequency content of springing response in heave degree of freedom occurs closer to the natural frequency in heave degree, which can result in fatigue failure of tethers.

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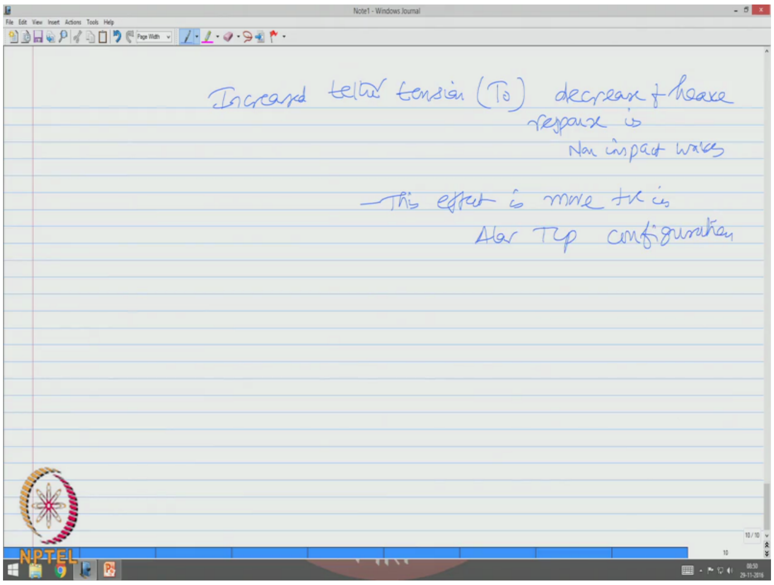

Increased tether tension results in decrease of heave response in non impact waves; however, this effect is more positive in triangular TLP configuration. So, friends we have seen distinctly 2 different kinds of responses, which happen in stiff degrees of freedom like pitch and heave; one under impact waves causing ringing, other under non impact waves causing springing response which can affect the safe functionality or operability of the platform as well as can result in tether pull out and fatigue failure of tethers.

Let us now extend this study on TLP again for extreme waves.

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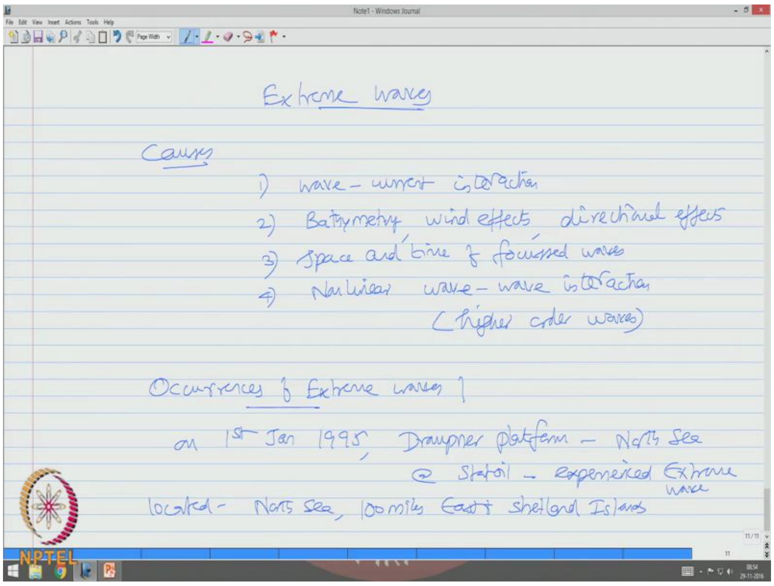

So, will quickly see what are extreme waves? What are the causes which can result in extreme waves? One could be due to wave current interaction. The second could be change in bathymetry, wind effects and wave directional effects. The third could be the space and time of focused waves can result in extreme waves; the fourth is very interesting non-linear wave-wave interaction, what we call as higher order waves can also result in extreme waves.

Now, the question comes have they occurred anywhere? Have such waves occurred anywhere? Answer is interesting; on first January 1995 Draupner platform, operating in North Sea at Statoil, location experienced an extreme wave. This platform is located in North Sea about 100 miles east of Shetland Islands.

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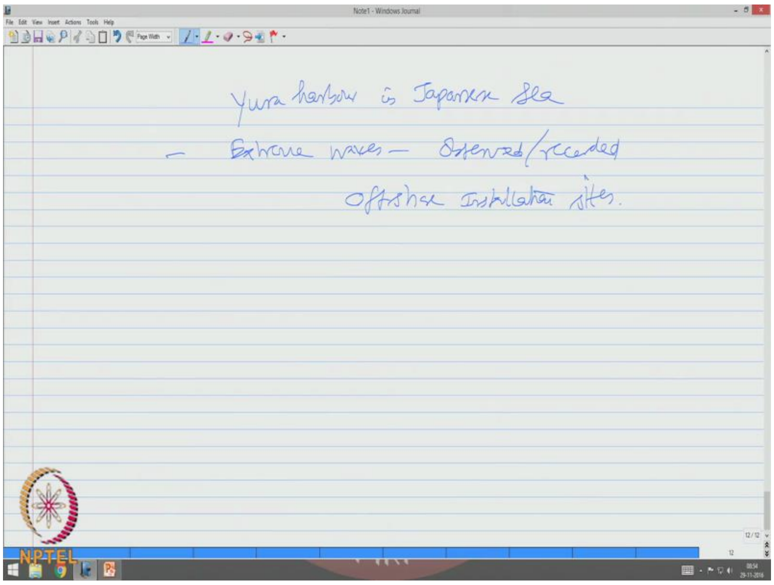

It is also seen again at Yura harbor in Japanese sea. So, such extreme waves are observed even recorded in offshore installation sites. So, friends it is interesting to be examine the platform response under such extreme waves. So, now, our study is more focused on how these waves are recorded, how equivalent waves of this type can be simulated and what is the validation of the simulated wave with that of the recorded wave, then is the simulation wave is fine let us see the response of the platform under these waves.

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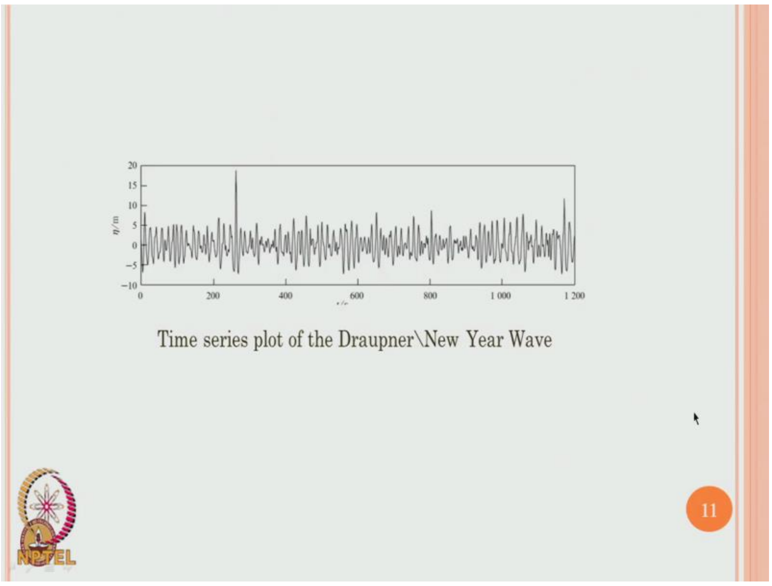

So, friends now I am showing you the time series plot of the Draupner wave, occur in the specific site location in North Sea. Since it occurred and recorded on first of January is also called as a New Year wave. So, that is a typical time history of sea surface elevation, which is got distinctly high peaks compared to that of the preceding and the successive waves. So, such extreme waves though occur though maybe random phenomena, but they do occur in offshore site conditions.

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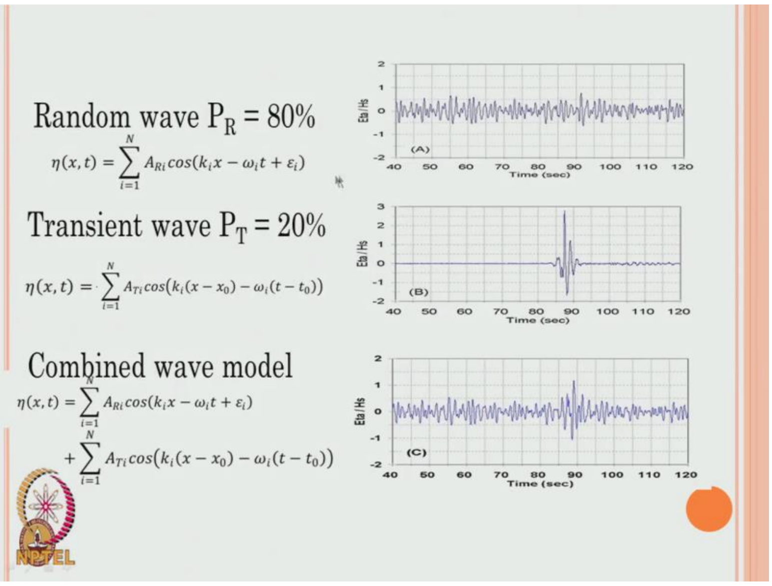

Now, issue comes how do you generate this waves or how do you simulate these waves before we understand that. Let us try to ask what are the effects of extreme waves?

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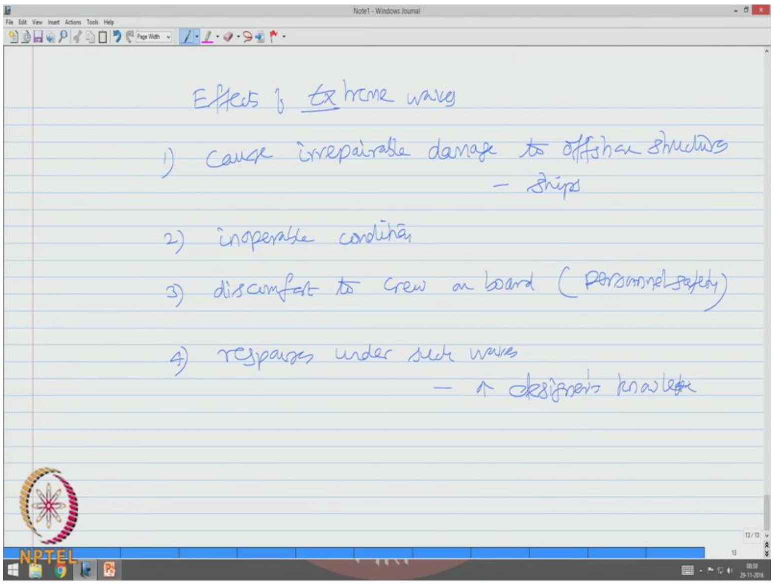

I mean why are we interested in studying the response under these extreme waves? These extreme waves are expected to cause irreparable damage to offshore structure, they can even effect sea going vessels, they may result in inoperable condition where the platform need to be shut down for a extreme operation it may of course, cause serious discomfort to the crew on board, which can challenge the personal safety therefore, responses under such waves will improve the designers knowledge, certainly without any doubt.

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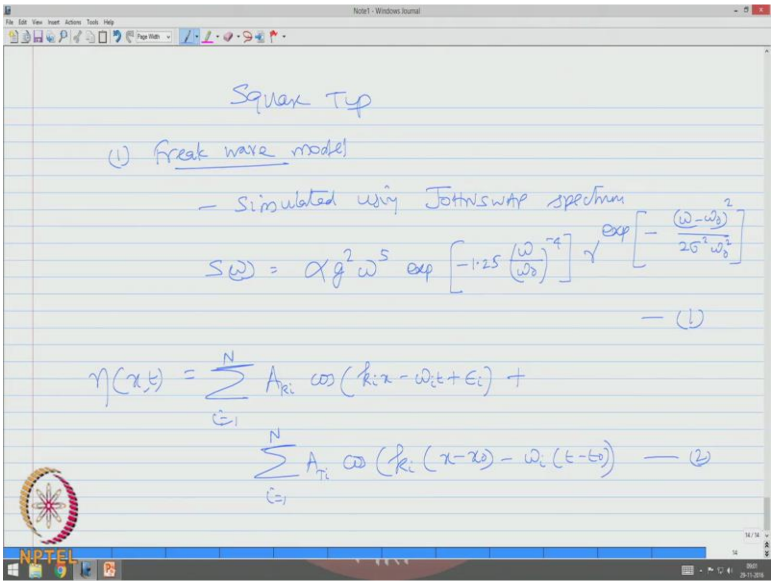

We will try to apply this waves on a square TLP, now how to generate this kind of waves? There are 2 models available in the literature; one is called freak wave model, this is simulated using Johnswap spectrum, the governing equation is given here, call equation 1. This is surface elevation simulated from this extreme wave from the spectrum is given by, which can be a function of space and time nothing, but the summation of series of waves, plus summation of again series of another set of waves which is got A Ti component, with cos k i, x of k i x minus x 0, minus omega i t minus t 0 - equation 2.

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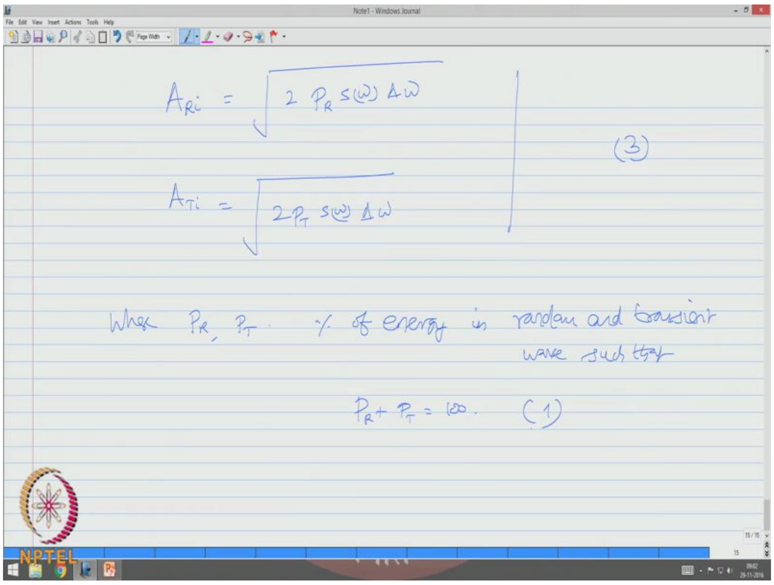

In this 2 equations A Ri is given by 2 P R S omega delta omega a spectral value and A Ti is given by 2 P T, S omega delta omega, where P R and P T are percentage of energy in the random and transient wave, such that the total percentage becomes 100 or let say at least factor of 1.

So, using this equations, spectrum is modified and generated and sea surface elevation is now shown on the screen; while generating the sea surface elevation, the random wave component and transient wave component kept as 80 and 20 percent, equations I have been used to generate random wave component separately and transient wave component separately and then they are super imposed to our combined sea surface elevation which looks like this. In this sea surface elevation at a chosen time one can very clearly see a distinctly high and extreme wave happening in a given simulated the set of series of waves.

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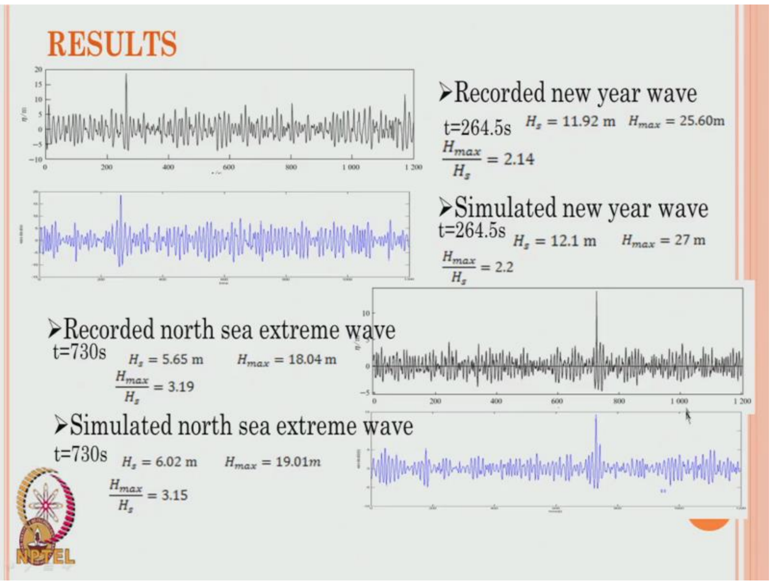

So, let us compare the simulated wave with that of recorded wave, New Year wave was recorded at time 264.5 seconds with significant wave height 11.92 meters; maximum wave height 25.6 meters and therefore, the ratio becomes 2.14. Using the spectral function and sea surface elevation a typical New Year wave is simulated exactly at 264.5 seconds, from this history can see here; the H s of the simulated wave is about 12.1 meter and H max is about 27 meter and the ratio is closely matching with the recorded new wave. Similarly, in north sea extreme wave was recorded at t is 730 seconds and H s, H max ratio being 3.19, a wave was simulated of the same nature using the equation shown in the slide exactly 730 seconds and the ratio is closely matching to that of the observed waves.

So, extreme waves a typical New Year wave observed at Draupner platform and a North Sea extreme wave which is also observed in Yura harbor in Japanese sea, where simulated and used for the loading occurring on TLP.

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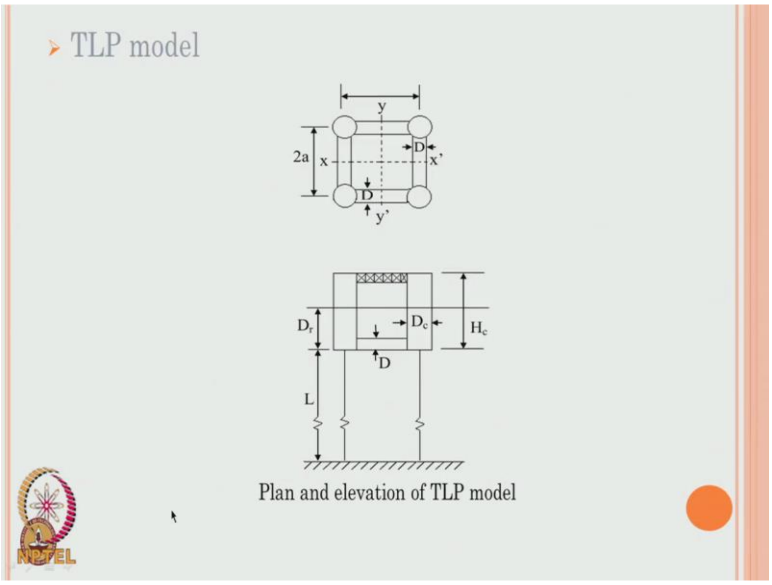

The TLP model is going to be a square model, which is shown in the screen now; all typical dimensions are borrowed from the standard literature.

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Geometric properties of TLP

Description	TLP_1	TLP_2	TLP_3
Weight (kN)	351,600.00	330,000.00	370,000.00
F_B (kN)	521,600.00	465,500.00	625,500.00
T_0 (kN)	170,000.00	135,500.00	255,500.00
Tether length l (m)	568.00	269.00	1,166.00
Water depth (m)	600.00	300.00	1,200.00
CG (m)	28.44	27.47	30.31
AE/l (kN/m)	84,000.00	34,000.00	45,080.00
Plan dim (m)	70.00	75.66	83.50
D_c (m)	17.00	16.39	18.80
r_x (m)	35.10	35.10	35.10
r_y (m)	35.10	35.10	35.10
r_z (m)	35.10	42.40	42.40

Natural periods of TLP

Degrees-of-freedom	TLP_1	TLP_2	TLP_3
Surge	100	87.20	132
Heave	3.10	1.96	3.11
Pitch	2.02	2.060	3.12

So, 3 TLP’s at various water depths, 300, double and further double are considered for the analysis.

The natural periods of these 3 TLP’s are given to me here in all the active degrees of freedom.

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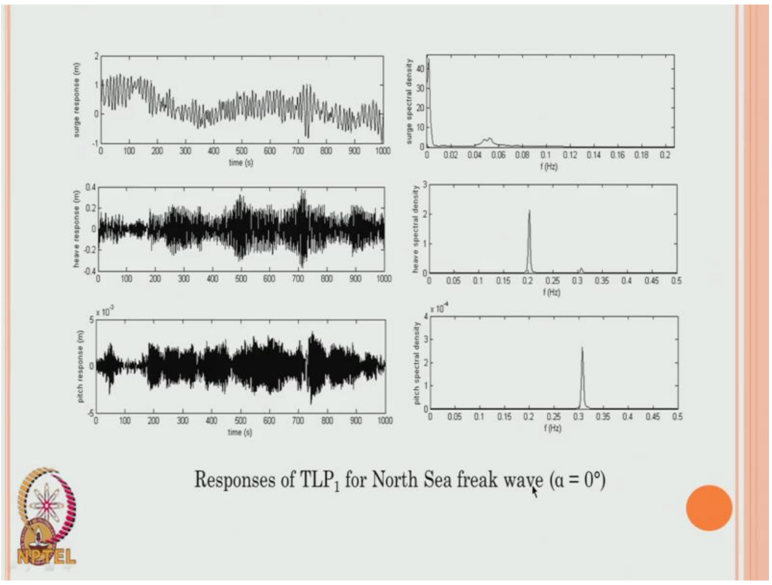

And the responses under north sea freak wave at instead angle of approach being zero is shown on 3 degrees of freedom and the corresponding power spectral density function in frequency domain is given. One can very clearly see this clear excitation of the heave frequency or power spectral density function of heave response under specific frequency whereas, in surge it is on the lower side and pitch is shifted from the top heave frequency for a north sea for TLP 1. For a new year waves simulated again a similar response is same of course, this is second response also seen in heave degree of freedom under the extreme waves generated as we saw just now.

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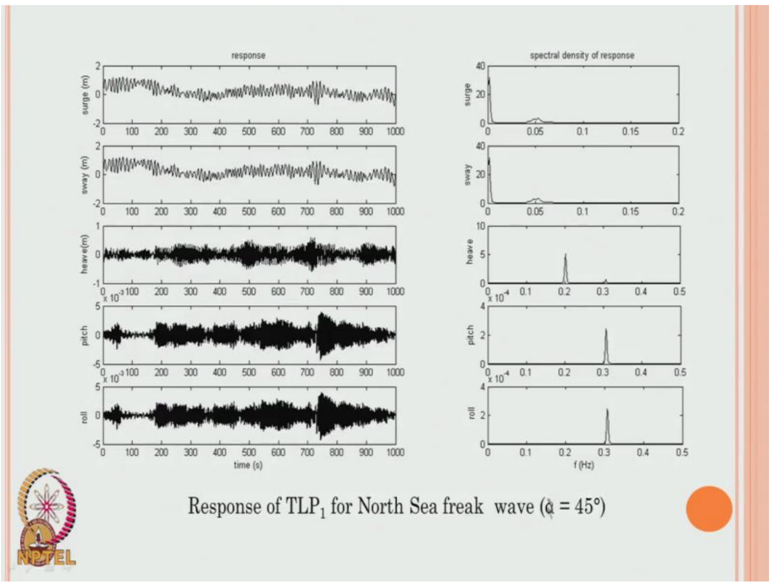

When you change the angle of approach, one can see all 6 degree of freedom now are active, yaw is not active because a platform is remain symmetric and one can see very clearly that there are second small peaks occurring in the heave still, which was also seen for wave approach angle of zero. So, extreme waves excited TLP nearer to a natural frequency in heave and pitch degrees of freedom, TLP is also seen to be sensitive for different wave directions under such extreme waves.

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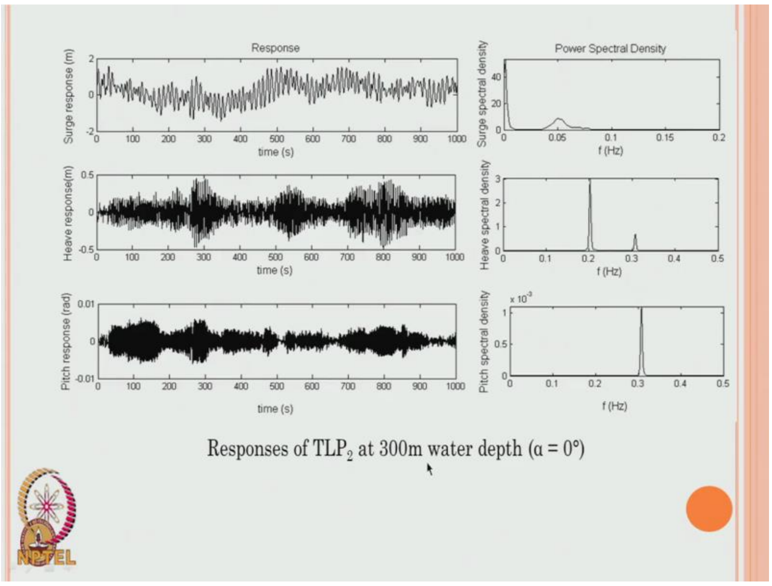

Responses of TLP_2 at 300m water depth (α = 0°)

There also sensitive respect to the water depth as you see here, the responses for deeper water depths are significantly different from the top shallow water depths.

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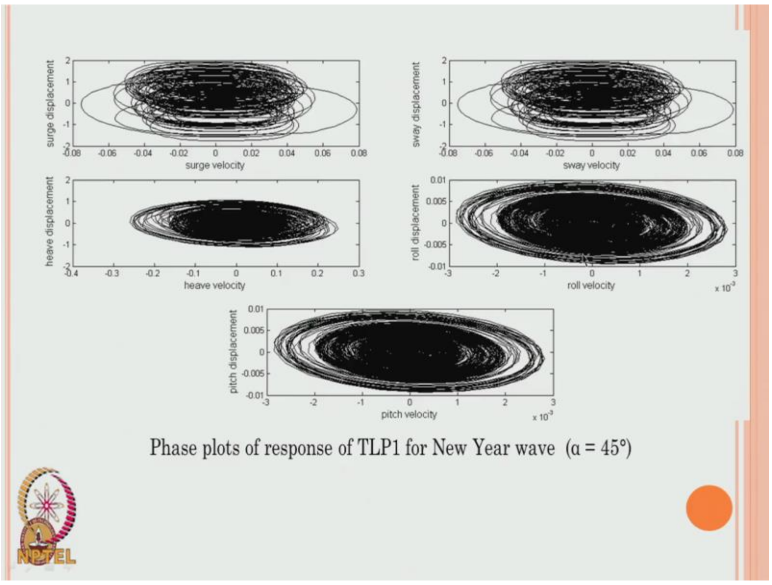

Phase plots of the response under New Year wave anyway showed in heave an extended elliptical approach, which shows the platform still remains stable, but however the platform is challenged on stiff degree of freedom as you see here.

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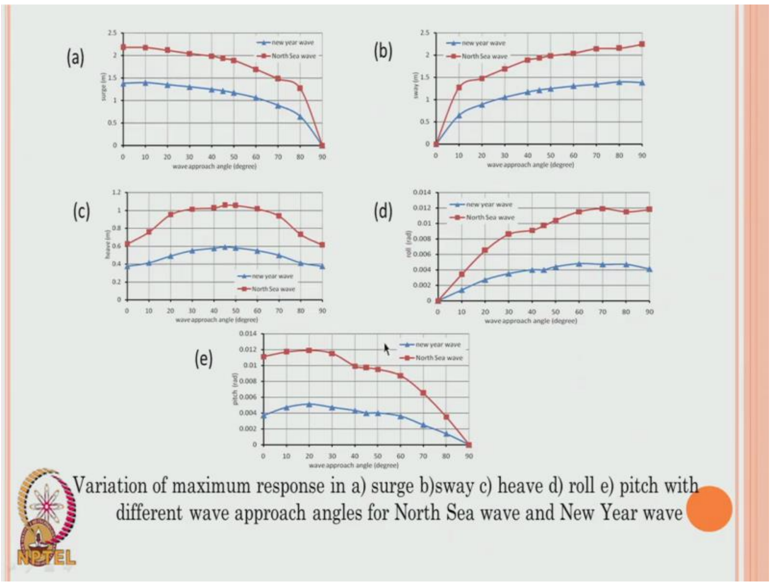

One can also see the maximum variation in the response under the New Year wave and North Sea wave, comparing these 2 in all 6 degrees of freedom. So, friends one can say that extreme waves.

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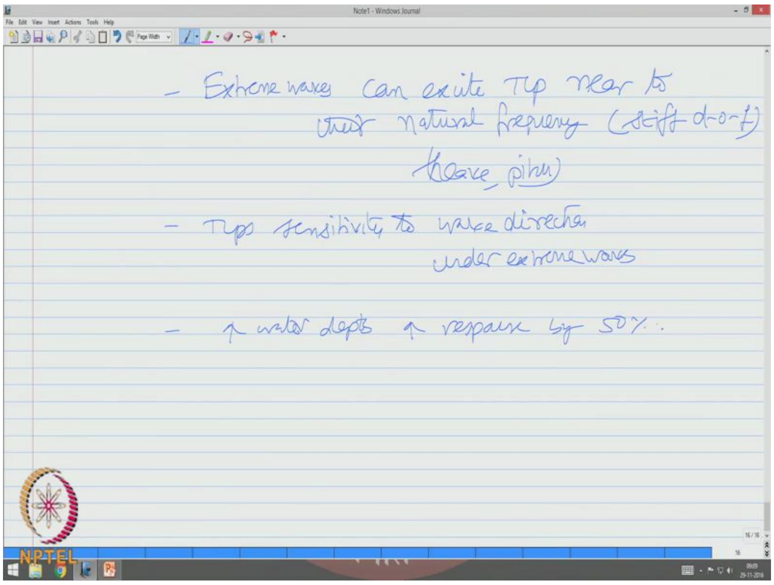

So, friend’s extreme waves can excite TLP near to their natural frequency in stiff degrees of freedom that is heave and pitch; in the studies what we just now saw TLP’s also showed sensitivity. So, wave direction under extreme waves, increase in water depth, increases the response by as high as about 50 percent.

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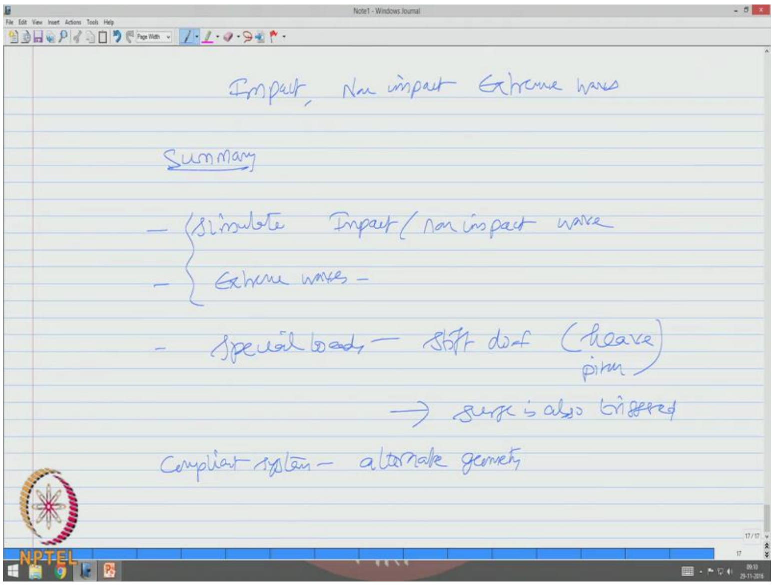

So, in this lecture we understood the responses under impact, non impact and extreme waves. So, friends if you look at the summary of this lecture we learned how to simulate the impact and non impact waves, how to simulate extreme waves using series of sea surface elevation super position, we understood that these set of waves which cause special loads in offshore structures, trigger stiff degrees of freedom especially heave and pitch and of course, since heave is coupled surge is also triggered.

So, a compliant system of an alternate geometry is also investigated. So, it is of interest to all offshore engineers that geometric optimization and the dynamic response behavior of these platforms under special loads caused by impact and non impact waves resulting in ringing and springing responses respectively is of a very high academic interest.

Thank you very much.